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Digital empowerment: the impact of rural digitization on the total factor productivity of agro-related enterprises

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Abstract

Rural digitization helps to enhance the efficiency of the use of digital resources in the agricultural industry, stimulate the endogenous development power of the traditional countryside, and then improve the total factor productivity of agro-related enterprises to achieve transformation and development. Based on an empirical study of panel data of agro-related enterprises among 235 A-share listed companies in China from 2011 to 2022, this paper analyzes the impact and mechanism of rural digitization on the total factor productivity of agro-related enterprises in terms of the multidimensional perspective of human capital, technological innovation and transaction costs. The results of the study show that the digital transformation of agro-related enterprises can significantly increase the total factor productivity of the enterprises, but its effect will be slightly different depending on the differences in ownership and regions. The study suggests that policy support for the digital transformation of agro-related enterprises should be increased, state-owned enterprises should be used as a model to lead the digital transformation of enterprises, the construction of digital countryside should be used as a basis to make up for differences in region, and the digitalization of countryside should be used as an opportunity to promote economic development.

Keywords

Rural digitization; agro-related enterprises; total factor productivity.

1. Introduction

At present, China is starting a new journey to build a modern socialist country in all aspects, and seeking high-quality development is the crucial theme of economic and social development during the Fourteenth Five-Year Plan period, so it is essential to speed up the promotion of high-quality development in the countryside and to facilitate the construction of the countryside to keep up with the pace of the construction of a modern socialist country. Rural digitization will promote the deep access of villages to the digital economy and their full integration into the digital era by promoting the construction of new infrastructure in villages and establishing a new mechanism for the online and offline integration of urban and rural resource elements.

According to Hu Delong and Shi Manzhen, the digital economy can effectively play the decisive role of the market in the allocation of resources, and marketization is an important mechanism of action for the digital economy to enhance the total factor productivity of enterprises[1]. Deng Xueqin et al. similarly point out that digital technology and the digital economy have had a profound impact on rural revitalization and have become important measures to promote rural development[2]. Rural digitization, as a new development model, is expected to enhance the total factor productivity of agro-related enterprises, and thus promote agricultural modernization and rural revitalization.

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2. Literature review

Scholars at home and abroad have explored topics related to digital villages and agricultural total factor productivity and put forward some constructive assertions. At present, academic research on the construction of digital villages mainly focuses on the following three aspects.

First, in the study of rural digitization and its impact effects. According to Han Jiaqi et al., the digital economy is regarded as a new driving force to consolidate the results of poverty alleviation and comprehensively promote rural revitalization[3]. Lu Xinyuan et al. affirmed that digital countryside construction can promote industrial prosperity and thus realize common prosperity through digital governance[4]. Xia Xianli et al. emphasized that building a digital countryside centered on digital industrialization and industrial digitization plays a significant role in promoting high-quality agricultural development[5]. Liu Jiping points out that the new digital economy enterprises represented by "Internet Plus" will effectively improve the efficiency of rural economic development[6].

Secondly, in the study of total factor productivity of enterprises and its influencing mechanism. Liu Naixi et al. find that foreign investment directly contributes to the total factor productivity progress of agribusinesses and that this contribution increases gradually over the years[7]. Han Yan et al. concluded from their study that innovation mediates all spillover effects of FDI on agribusiness productivity[8]. Jiang Hongli et al. emphasize that financial technology can enhance the total factor productivity of enterprises by alleviating financing constraints[9].

Third, in the study of rural digitization and total factor productivity of enterprises. Jin Shaorong et al. argued that digital transformation can increase agribusiness total factor productivity by improving capital utilization, among other things[10]. Sun Shuhui and Chen Xiaonan found that, based on spatial correlation network, there is a significant spatial autocorrelation in the digital countryside, which can significantly improve the green total factor productivity of local agriculture[11]. Guo Haihong emphasized that digital countryside construction can either directly promote agricultural total factor productivity or indirectly promote agricultural green total factor productivity by leading to green technological advances[12].

It can be seen that, regarding the relationship between rural digitization and total factor productivity of agro-related enterprises, a number of studies have been conducted to provide reference paths for contemporary Chinese countryside to realize digital transformation from different dimensions. However, there are relatively few studies on the link between rural digitization and total factor productivity of agro-related enterprises, and they are not specifically refined to the countryside and agro-related enterprises. Accordingly, this study innovates from the perspective to further address the traditional-to-modern transformation of agro-related type enterprises, deeply researches the theoretical mechanism between rural digitization and the total factor productivity of agro-related enterprises, and draws corresponding conclusions and recommendations through empirical analysis.

3. Theoretical analysis

Enterprise total factor productivity is an important characterization of an enterprise's capacity for technological innovation and managerial change. Guo Qingwang and Jia Junxue pointed out that the core connotation of total factor productivity lies in the increase in output due to technological progress and capability realization, etc., in addition to factor inputs such as capital and labor, and it is the residual obtained by removing the contribution of factor inputs[13]. Therefore, technological progress and efficiency improvement are key to promoting total factor productivity growth in agro-related enterprises. Based on this, this paper mainly deconstructs the inherent logical relationship between rural digitization and total factor productivity of agro-

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related enterprises from the three dimensions of human capital, technological innovation and transaction costs.

3.1. Human capital effect

The accumulation of human capital is one of the sources of economic growth. Xu Hao found that rural digitization has an obvious "learning by doing" effect, which can empower the accumulation of traditional agricultural capital and rural human capital and enhance the productivity of rural labor[14]. Among the various factors of production for agricultural development, human capital is the most dynamic and creative. When the human capital level of agro-related enterprises is low, the enterprises' weak digital awareness and insufficient ability to use digital, it is difficult to bring into play the advantages of digital technology in eliminating the information barriers of agricultural products, and it will also magnify the natural and market risks of agricultural production decisions, which is not beneficial to the production of agro-related enterprises. When the human capital level of agro-related enterprises is high, the relevant practitioners can better adapt to the digital scene and reasonably put into the use of agricultural production, timely judgment and risk avoidance based on market signals, and carry out intelligent agricultural production and management. The construction of digital countryside supports the development of agro-related enterprises and service entities, strengthens the emphasis on highly digitally literate talents with organizational and operational capabilities, service capabilities and innovation capabilities, and thus achieves a significant increase in the total factor productivity of enterprises.

3.2. Technological innovation effect

Rural digitization is a strong support for the evolution and advancement of modern agricultural technology, and digital technology has become a core driver of agricultural technological progress. First, Yu Yongze et al. clarified that Internet technology helps intra-regional knowledge and technology spillovers, realizes the sharing of innovative resources and long-distance spread of technology, bridges the digital divide in rural areas, and enhances digital accessibility, thus effectively shortening the R&D cycle of agricultural production technology for agro-related enterprises[15]. Secondly, digital technology permeates all aspects of agricultural production and promotes more efficient resource allocation. The application of information technology, such as artificial intelligence, 5G, Internet of Things, and big data, provides a technological foundation that makes agricultural production smarter and more convenient. Finally, Yin Xiangfei and Duan Wenbin suggest that advanced technology and management methods promote total factor productivity growth by improving the efficiency of input factors[16]. Managers of agro-related enterprises understand the various stages of production based on the digital services and decision-making data provided in real time, so as to realize precise agricultural production and promote high-efficiency, high-quality and high-level production of enterprises, thus effectively increasing the total factor productivity of agro-related enterprises.

3.3. Transaction cost effect

Enterprise production must take into account the transaction costs it faces. Transaction costs arise mainly from market transactions and internal management processes of the enterprise. From the perspective of market transactions, the rural digitization has accelerated the deep integration of market information, factors and products, prompting a more open and transparent trading market. Han Lu et al. found that agro-related enterprises can easily find upstream and downstream trading objects that match their needs in the market through big data, which improves the transaction efficiency between enterprises and greatly reduces the cost of information collection, capital financing, and logistics and transportation, and realizes the effect of economies of scale[17]. At the same time, the use of information technology can

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also directly reduce the communication costs between the production side and the consumer side. Agro-related enterprises can utilize digital technology to integrate and match information, accurately understand consumer demands, improve user experience, enhance user stickiness and reduce marketing and promotion costs. From the perspective of internal company management, the rural digitalization profoundly affects the change of the internal production and operation mode of the enterprise, which makes the organization mode of the enterprise tend to be networked, flattened and flexible, eases the information asymmetry problem of the operation activities, and then promotes the growth of the total factor productivity of the enterprise.

4. Research design

4.1. Model setup

Based on the theoretical analysis and research assumptions above, this paper constructs a benchmark regression model of the following form:

$$TFP_{ijt} = \beta_0 + \beta_1 digit_{it} + \sum \beta_i Control_{ijt} + \mu_i + \delta_t + \theta_j + \varepsilon_{ijt} \quad (1)$$

Where i, j, and t represent enterprises, provinces, and years, respectively; TFP_{ijt} is the core explained variable, representing the total factor productivity of enterprises in the year, denoted as TFP; $digit_{it}$ is the core explanatory variable, representing the digital transformation index of enterprises in the year; $Control_{ijt}$ represents a series of control variables selected in this paper, μ_i is the individual fixed effect, δ_t is the year fixed effect, θ_j is the province fixed effect, and ε_{ijt} is the random error term.

This paper takes agro-related enterprises in A-share listed companies as the research sample, and selects the data of listed companies with industry labeling code A, C13 and C14 for the study based on the industry classification codes of the Guidelines for Industry Classification of Listed Companies (2012 Revision) formulated by the Securities and Exchange Commission (SEC), with the sample spanning the period of 2011-2022. In order to ensure the scientific rationality of the data, this paper excludes ST enterprises as well as PT enterprises, and excludes the years in which the business scope is not agro-related, a total of 235 samples of agro-related enterprises are screened out, totaling 1453 observations. The data in this paper comes from the China Stock Market & Accounting Research Database and the China Agricultural Statistics Yearbook, etc.

4.2. Variable measurement

4.2.1. Explained variables

Confined to research methods and data, representative methods for measuring TFP include methods such as OP and LP. LP method can effectively solve the bias problem brought by enterprises adjusting capital stock and production at the same time, and also can avoid the defect of OP method which requires that investment must be greater than 0 and excludes samples. Therefore, this paper adopts the LP method to measure the TFP of enterprises, and the model is as follows:

$$lnY_{st} = \lambda_0 + \lambda_1 lnL_{st} + \lambda_2 lnK_{st} + \lambda_3 lnM_{st} + \omega_{st} \quad (2)$$

where Y is the income from main operations; L is the labor input, measured by the number of employees; K is the capital input, measured by the net fixed assets; M is the intermediate input, which is the sum of four items, namely, operating costs, selling expenses, administrative expenses, and financial expenses, minus depreciation and amortization, as well as cash paid to employees; and ω_{st} denotes the random error term.

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4.2.2. Explanatory variables

Given the availability of data, this paper uses data from the Digital Transformation Research Database of Listed Companies in China, which reports relevant content based on announcements published in the China Statistical Yearbook, annual reports of listed companies, fund-raising announcements, and qualification certifications.The database constructs the digital transformation index indicator system and weights from six dimensions: strategic leadership, technology drive, organizational empowerment, environmental support, digital achievement and digital application. The core explanatory variable of this paper is its digital transformation index, denoted as DTI.

4.2.3. Control variables

In this paper, control variables that bring impact on enterprise TFP are selected from macro-environment and micro-firm level. The control variables include:(1) Enterprise age - the longer the enterprise is established, the more conducive to the accumulation of enterprise technology and management experience, which in turn improves enterprise TFP; (2) Net profit margin of total assets - this indicator reflects the profitability of the enterprise, usually the better the profitability, the higher enterprise TFP; (3) Operating income growth rate - operating income growth implies that the business situation of the enterprise improves and the market scale expands, which is positively correlated with the enterprise TFP; (4) Total asset turnover - the higher the total asset turnover rate, which often means that the asset utilization efficiency is higher, it has a positive impact on TFP; (5) Asset gearing ratio - excessive debt ratio will increase the pressure of debt repayment, which is not conducive to enterprise development, but a certain degree of debt financing can promote enterprise expansion and reduce enterprise costs, which is conducive to improving enterprise TFP; (6) Administrative expense ratio - Lower management expense ratio can save enterprise funds and improve enterprise competitiveness. The calculation of each control variable is shown in Table 1.

Table 1 Names and descriptions of control variables

Control Variables	Variable Description
Enterprise age	Current year - Year of establishment of the enterprise
Net profit margin of total assets	Net profit/Average balance of total assets
Operating income growth rate	Current year's operating income/Previous year's operating income -1
Total asset turnover	Operating income/Average total assets
Asset gearing ratio	Year-end total liabilities/Year-end total assets
Administrative expense ratio	Administrative Expense/Operating Income

Descriptive statistics of all the variables involved in the text are shown in Table 2.The average value of total factor productivity is 6.572, and the maximum value is about 2.6 times the minimum value, indicating that there is a large gap in TFP among enterprises; the average value of the main explanatory variable, digital transformation index, is 29.55, and the maximum value is about 2.4 times the minimum value, indicating that there is a large difference in the digital transformation index of enterprises.

Table 2 Descriptive statistics of variables

variables	sample size	average	median	standard deviation	maximum	minimum
TFP	1328	6.572	6.535	0.794	3.435	9.142

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variables	sample size	average	median	standard deviation	maximum	minimum
DTI	1453	29.55	27.41	5.715	21.55	52.11
Enterprise age	1453	18.56	18	5.525	2	38
Net profit margin of total assets	1364	0.0390	0.0380	0.0750	-0.226	0.242
Operating income growth rate	1364	0.145	0.105	0.320	-0.561	1.783
Total asset turnover	1364	0.807	0.670	0.570	0.0830	2.982
Asset gearing ratio	1453	0.386	0.375	0.198	0.0390	0.938
Administrative expense ratio	1453	0.0760	0.0570	0.0670	0.0130	0.467

5. Analysis of empirical results

Note: In the empirical analysis of this paper, the numbers in parentheses are t-values; ***, **, and * denote significance levels of 1%, 5%, and 10%, respectively. Control variables were added to all regressions and controlled for enterprise, year and province fixed effects.

5.1. Benchmark regression analysis

In this paper, the theoretical model is used for regression analysis and the regression results are shown in Table 3. After gradually adding control variables and enterprise, year, and province fixed effects, the regression results are all significant, indicating that enterprise digital transformation can effectively improve enterprise TFP, which is consistent with the previous theoretical analysis. From the results of the control variables, the coefficients of the digital transformation index and its squared term are significant, indicating that digital transformation has a nonlinear effect on firm TFP; the regression results of enterprise-level control variables, such as enterprise age, are also in line with the expectations of theoretical analyses, which, to a certain extent, indicates the reliability of the regression results.

Table 3 Benchmark regression results

	(1)	(2)	(3)	(4)
DTI	0.0336***	0.0322***	0.0279***	0.0224***
	(9.00)	(9.10)	(10.50)	(9.29)
Enterprise age		0.0255***	0.0295***	0.0274***
		(7.05)	(11.40)	(12.02)
Net profit margin of total assets		2.622***	0.823***	1.463***
		(9.90)	(3.66)	(6.34)
Operating income growth rate			0.134*	0.00596
			(2.53)	(0.13)
Total asset turnover			0.912***	0.697***
			(29.86)	(24.66)
Asset gearing ratio				0.845***
				(10.39)
Administrative expense ratio				-3.041***
				(-12.73)

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	(1)	(2)	(3)	(4)
DTI	0.0336***	0.0322***	0.0279***	0.0224***
	(9.00)	(9.10)	(10.50)	(9.29)
Enterprise age		0.0255***	0.0295***	0.0274***
		(7.05)	(11.40)	(12.02)
Net profit margin of total assets		2.622***	0.823***	1.463***
		(9.90)	(3.66)	(6.34)
Enterprise/year/province fixed effects	No	No	No	Yes
constant term	5.568***	5.030***	4.399***	4.667***
	(49.18)	(39.50)	(45.15)	(50.51)
sample size	1327	1327	1327	1327
R^2	0.0601	0.1536	0.5598	0.6304

5.2. Endogenous analysis

Benchmark regression results suggest that enterprise digital transformation can significantly affect the level of enterprise TFP, but there may be endogenous issues due to reverse causality. Therefore, in this paper, the average value of digital transformation of enterprises in the same industry in the same year and in the same province in the same year, except for the enterprises themselves, is selected as an instrumental variable to mitigate possible endogenous problems. First of all, the average value of digital transformation in the same industry in the same year can represent the average level of digital transformation in the industry, and enterprises in industries with a high average value have a higher probability of having a high level of digital transformation themselves. Similarly, the average value of digital transformation in the same province in the same year represents the average level of digital transformation in that province, and enterprises in provinces with a high average value have a higher probability of having a high level of digital transformation themselves. Thus, the digital transformation average satisfies the relevance requirement as an instrumental variable. Second, since the calculation of the digital transformation average excludes its own enterprise, the average does not have a direct impact on the TFP of that enterprise. Therefore, both averages satisfy the exogenous requirement of being an instrumental variable.

Two-stage least squares estimation was performed on the two instrumental variables and the estimation results are shown in Table 4, respectively. The results show that the coefficient of the effect of digital transformation on the TFP of agro-related enterprises is positive and significant, suggesting that the conclusion that digital transformation can significantly increase the TFP of agro-related enterprises still stands. In other words, the contribution of digital transformation to the TFP of agro-related enterprises is robust.

Table 4 Instrumental variable regression results

	(1)One-stage regression:DTI	(2) Two-stage regression:TFP	(3)One-stage regression:DTI	(4)Two-stage regression:TFP
Instrumental variable 1	0.335***			
	(3.87)			
Instrumental variable 2			0.127***	
			(5.26)	
DTI		0.109***		0.124***

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	(1)One-stage regression:DTI	(2) Two-stage regression:TFP	(3)One-stage regression:DTI	(4)Two-stage regression:TFP
		(4.54)		(5.89)
Weak instrumental variables test (F-value)		25.7517		40.6096
Over-identification test (p-value)		0.5847		0.5859
Sample size	1327	1327	1327	1327
R^2	0.0547	0.2414	0.0632	0.1020

5.3. Robustness test

5.3.1. Substitution of explanatory variables

The regression was conducted using the digital achievement score and digital application score from the digital transformation research database of Chinese listed companies, respectively, and the results are shown in Table 5-1. It can be seen that the role of digital transformation on TFP remains significantly positive, so the conclusion of this paper is robust.

Table 5-1 Robustness test results

	(1)TFP_LP	(2)TFP_LP
Digital achievement score	0.0145*** (5.20)	
Digital application score		0.00848*** (5.98)
Sample size	1327	1327
R^2	0.6401	0.6431

5.3.2. .Replacement of explained variables

The traditional OLS method and OP method are used to calculate enterprise TFP respectively , and the results are shown in Table 6-2. It can be seen that the effect of digital transformation on TFP is still significantly positive, so the conclusion of this paper is robust.

Table 5-2 Robustness test results

	(1)TFP_OLS	(2)TFP_OP
DTI	0.0395*** (10.53)	0.0297*** (9.92)
Control variable	Yes	Yes
Sample size	1327	1327
R^2	0.6588	0.6734

5.3.3. .Exclusion of 2020 data

Due to fewer statistical indicators in the 2020 CAGS and the fact that enterprises were hit by a sudden epidemic in 2020, this may affect the robustness of the conclusions. In this paper, in

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order to retain as much of the sample as possible, the samples are not excluded from the benchmark regression, whereas they are excluded from the robustness test, and the results of the excluded regressions are shown in column (1) of Table 5-3. It can be seen that the effect of digital transformation on TFP remains significantly positive, so the conclusion of this paper is robust.

5.3.4. Addition of missing variables

The size of the enterprise usually concerns the management system and economic efficiency of the whole enterprise, which affects the development of the enterprise to a certain extent, and is also an important distinguishing index that may affect the accuracy of the research conclusions. Therefore, re-estimation is performed after the missing variable of enterprise size is added to the control variables, and the results are shown in column (2) of Table 5-3. It is evident that enterprise digital transformation can still significantly contribute to the improvement of enterprise TFP.

Table 5-3 Robustness test results

	(1)TFP_LP	(2)TFP_LP
DTI	0.0222***	0.00724***
	(8.65)	(3.94)
Enterprise size	No	0.339***
		(28.11)
Sample size	1195	1327
R^2	0.6539	0.7910

5.4. Heterogeneity analysis

5.4.1. Heterogeneity of ownership

In China, state-owned enterprises(SOEs) are not aiming at profit maximization, but put more importance on stabilizing employment and safeguarding the country's economy and people's livelihood; non-state-owned enterprises(non-SOEs) are generally aiming at profit maximization and are more responsive to market-oriented reforms. As shown in columns (1) and (2) of Table 6-1, this suggests that undertaking digital transformation has a significant contribution to raising TFP for both SOEs and non-SOEs, but slightly more so for SOEs. The reasons for this may be twofold: first, in the process of digital transformation, SOEs are able to obtain policy and financial support, while non-SOEs, although inclined to take the initiative in applying digital technology to improve efficiency, are limited to a variety of factors such as funding, technology and policy, and their transformation is slower than that of SOEs. Second, the digital transformation has increased the degree of marketization, increased the competition faced by SOEs, and further stimulated the vitality of SOEs, with stronger effects than the promotion of non-SOEs.

Table 6-1 Heterogeneity analysis results

	(1)SOE's TFP	(2)non-SOE's TFP	(3)LSE's TFP	(4)SSE's TFP
DTI	0.0246***	0.0230***	0.0153***	0.0107***
	(5.36)	(8.10)	(5.17)	(3.64)
Sample size	434	893	639	688
R^2	0.6586	0.6654	0.6085	0.6695

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5.4.2. Heterogeneity of scale

A large-scale enterprise(LSE) implies that it has a large number of employees and a large scale of assets, while its management system is more complete compared with that of a small-scale enterprise(SSE). As shown in columns (3) and (4) of Table 6-1, this suggests that undertaking digital transformation has a significant effect on improving TFP for both LSEs and SSEs, but more so for LSEs. The reasons for this may be twofold: first, knowledge spillovers and technology diffusion are stronger in large-scale firms than in small-scale firms after the introduction of digital technologies. As digital applications become commonplace within companies, it is easier for LSEs to develop a price advantage and thus increase revenue and market share, which in turn boosts TFP. Second, LSEs tend to have higher credit ratings and usually have easier access to capital and credit, enabling them to mobilize more resources for technological upgrading and transformation. And LSEs are typically more risk-responsive and able to mitigate losses more quickly and effectively when anomalies arise during digital transformation. In contrast, SSEs tend to lack the ability to cope with risk, so digital transformation is less effective in improving TFP for SSEs.

Table 6-2 Heterogeneity analysis results

	(1)Eastern TFP	(2)Central TFP	(3)Western TFP
DTI	0.0153***	0.0255***	0.0225***
	(4.67)	(5.49)	(3.82)
Sample size	714	294	319
R^2	0.6713	0.7334	0.6120

5.4.3. Heterogeneity of region

Drawing on Shen Xiaobo et al., this paper groups enterprises into Eastern, Central and Western regions for regression[18]. As shown in Table 6-2, this indicates that digital transformation for agro-related enterprises has a significant contributing effect on TPF improvement for both eastern, central and western enterprises, but is more favorable to TPF improvement in the central and western regions. The reasons for this may be twofold: first, the eastern region has a strong economic base and high technological level, and enterprises are able to improve their TFP through the agglomeration effect, industrial upgrading, and the introduction of technology, etc., and digital transformation is only one of the ways of development. The central and western regions have less development opportunities and fewer resources, so once the digital transformation is carried out, it will bring rapid growth in the economic efficiency of enterprises, and the enhancement of TFP will be greater compared with the eastern region. Second, the eastern region has gathered many high-tech industries, and the state introduced policies earlier to support the development of the digital economy in the eastern region, so enterprises in the eastern region are generally involved in digital transformation. The growth rate of benefits from digital transformation has declined as new production methods brought about by the digital economy have merged with enterprises in the East. The digital transformation of enterprises in the Midwest started later and is in the stage of rapid growth, so the impact of digital transformation on TPF improvement in the Midwest is more obvious.

5.5. Mechanism analysis

According to the previous theoretical analysis, digitalization affects TFP of agro-related enterprises through the triple effect of human capital, technological innovation and transaction costs. In this paper, three indicators, including human capital level, technological innovation efficiency and transaction cost index, are selected to analyze the mechanism respectively. With reference to the calculation method of enterprise digital transformation index database, this paper constructs the evaluation system of enterprise human capital level and measures the

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human capital level of agro-related enterprises. Human capital levels are in part indicative of the improved human and capital allocation aspects that digital transformation brings to an enterprise. According to the regression results in column (1) of Table 7, enterprise digital transformation can significantly increase the level of human capital, i.e., enterprise digital transformation can contribute to the increase of enterprise TFP by affecting the level of human capital.

Table 7 Mechanism analysis results

	(1)human capital level	(2)technological innovation efficiency	(3)transaction cost index
DTI	0.148***	0.254***	0.0648***
	(7.11)	(7.79)	(3.77)
Sample size	1364	1364	1364
R^2	0.0783	0.1292	0.0329

From the aforementioned theoretical analysis, it can be seen that the market mechanism can stimulate technological innovation and accelerate the diffusion of technology, drive the development of the industry, and improve the TFP through technological progress. This paper organizes the technological innovation efficiency of each agro-related type of enterprise from 2011 to 2022 based on the China Agricultural Statistical Yearbook. Technological innovation efficiency is based on technological inputs and innovation outputs and other micro-data measurements, so this paper as a proxy variable for technological innovation, in the mechanism of the analysis process of the innovation index plus 1 and then take the logarithmic treatment. The regression results, as shown in column (2) of Table 7, indicate that enterprise digital transformation can promote technological innovation and technology diffusion. In this paper, the enterprise transaction cost index is used as a proxy variable for the efficiency of enterprise resource allocation, and the absolute value of the difference between the actual transaction cost and the transaction efficiency is used to indicate the degree of deviation from the transaction cost, and the higher the degree of deviation, the lower the transaction efficiency. The results, as shown in column (3) of Table 7, indicate that enterprise digital transformation can increase enterprise TFP by reducing transaction costs.

6. Conclusions and policy recommendations

Taking agro-related enterprises in A-share listed companies as the research sample, this paper studies the impact of rural digitization on the total factor productivity of agro-related type enterprises and draws the following conclusions: (1) enterprise digital transformation can significantly enhance enterprise TFP; (2) conducting digital transformation has a significant facilitating effect on both state-owned and non-state-owned enterprises to enhance TFP, but the facilitating effect is more beneficial to state-owned enterprises; (3) digital transformation has a significant facilitating effect on the TFP of both large-scale and small-scale agro-related enterprises, but the facilitating effect is more obvious to large-scale enterprises; (4) agro-related enterprises conducting digital transformation has a significant promotion effect on the TFP improvement of both eastern, central and western enterprises, but it is more conducive to the TFP improvement in the central and western regions; (5) the digital transformation of enterprises can promote the improvement of enterprise TFP by influencing the level of human capital, promoting technological innovation and technology diffusion, and improving the efficiency of enterprise resource allocation.

(1)Increase policy support for the digital transformation of agro-related enterprises. The government should set up special funds to support digital transformation projects of agro-

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related enterprises to reduce the cost and risk of transformation. Incentives such as tax breaks and loan concessions should also be provided to encourage more agro-related enterprises to actively engage in digital transformation. Digital infrastructure construction in rural areas, including network coverage, data centers and cloud computing platforms, should be strengthened to provide strong support for the digital transformation of agro-related enterprises. Optimizing the supply of digital transformation services, the government can guide and support third-party service providers to provide digital transformation consulting, program design, technical support and other services for agro-related enterprises to help them formulate appropriate transformation strategies and improve total factor productivity.

(2) Emphasize differentiated support for SOEs and non-SOEs. Given that digital transformation has a greater role to play in promoting SOEs, the government can give more support and guidance to SOEs in terms of policy, while not neglecting the support for non-SOEs to ensure that all types of enterprises can enjoy the dividends of digital transformation.

(3) Pay attention to regional development differences and apply differentiated policies. For agro-related enterprises in the eastern, central and western regions, the government should formulate differentiated digital transformation policies according to the actual situation and development needs of the localities. Especially for the central and western regions, policies should be tilted more strongly to promote their agro-related enterprises to realize digital transformation more quickly and enhance the total factor productivity of enterprises.

(4) Strengthen the training and introduction of talents. The government should increase the cultivation of agricultural digitalization talents, while actively introducing external talents to provide talent protection for the digital transformation of agro-related enterprises. Second, in order to promote technological innovation and technology diffusion, the Government should encourage agro-related enterprises to strengthen technological innovation, promote the application and diffusion of new technologies in the agricultural sector, and facilitate the sharing and dissemination of advanced technologies among agro-related enterprises. At the same time, the Government should guide agro-related enterprises to optimize resource allocation and improve the efficiency of resource utilization. It should promote the in-depth integration of agro-related enterprises with other industries, realize resource sharing and complementary advantages, and improve the overall competitiveness of agro-related enterprises.

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